

POLTOP: AIRSAR Polarimetric Interferometry

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Abstract

The NASA/JPL AIRSAR system was upgraded to collect polarimetric interferometric data from the June 98 deployment. In this paper, we present the overview of the POLTOP (AIRSAR polarimetric interferometry mode) mode: basic theory, implementation and calibration, and radar signatures. Based on the data collected in Ontario, California, it is clear that the interferometric information varies significantly depending upon the radar polarization state. Since we are still in the process of calibrating the POLTOP data, the results shown in this paper are preliminary. The proposed calibration algorithm and the radar signature are also briefly discussed.

Basic Theory

SAR interferometry can be mathematically expressed as the cross correlation of two radar measurements from antennas separated in the cross track direction as shown in equation (1).

$$\begin{bmatrix} s_1 \\ s_2 \end{bmatrix} \begin{bmatrix} s_1^* & s_2^* \end{bmatrix} = \begin{bmatrix} s_1 s_1^* & s_1 s_2^* \\ s_1^* s_2 & s_2 s_2^* \end{bmatrix} \quad (1)$$

where s_1 and s_2 are two interferometric measurements. The diagonal terms are usual SAR images and the phase of the off-diagonal term provides the topographic information. From the off-diagonal term, the normalized correlation coefficient γ can be defined as

$$\gamma = \frac{\langle s_1 s_2^* \rangle}{\sqrt{\langle s_1 s_1^* \rangle \langle s_2 s_2^* \rangle}} = \gamma_s \gamma_n \gamma_t \quad (2)$$

where $\langle \bullet \rangle$ denotes the average over many pixels. The interferometric correlation coefficient can be decomposed into three terms: the scattering decorrelation ($1 - \gamma_s$), the thermal noise decorrelation ($1 - \gamma_n$), and the temporal decorrelation ($1 - \gamma_t$). For a single pass interferometer like the TOPSAR system, the temporal decorrelation is negligibly small. For polarimetric interferometry [1], equation (1) can be rewritten as

$$\begin{bmatrix} \bar{s}_1 \\ \bar{s}_2 \end{bmatrix} \begin{bmatrix} \bar{s}_1^+ & \bar{s}_2^+ \end{bmatrix} = \begin{bmatrix} \bar{s}_1 \bar{s}_1^+ & \bar{s}_1 \bar{s}_2^+ \\ \bar{s}_1^+ \bar{s}_2 & \bar{s}_2 \bar{s}_2^+ \end{bmatrix} \quad (3)$$

where the superscript symbol + denotes the transpose complex conjugate operator and

$$\bar{s} = \begin{bmatrix} s_{hh} \\ s_{hv} \\ s_{vv} \end{bmatrix} \quad (4)$$

for the backscattering case where $s_{hv} = s_{vh}$.

Polarimetric Interferometry Implementation and Calibration

In order to implement polarimetric interferometry at C-band, we combined the "ping-pong" TOPSAR and SAR polarimetry. That is, we collected the polarimetric data for both top and bottom antennas in the "ping-pong" sequence as shown in Fig. 1.

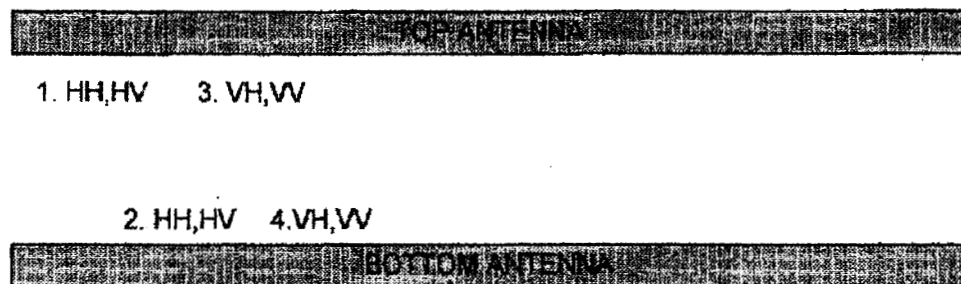


Fig. 1. Operation sequence of the POLTOP mode. During the four radar operations (1, 2, 3, and 4), the aircraft moves approximately 1/3 of the antenna length.

Notice that the POLTOP pulse repetition frequency (PRF) is twice as high as the PRF of the usual polarimetric SAR. Therefore, the data-limited swath is only half of the usual swath. In the future, the four bit BFPQ (Block Floating Point Quantization) must be implemented to collect the data over the entire swath. Since the cross polarization component has to be measured, the higher SNR (Signal to Noise Ratio) will be very useful for the POLTOP operation.

We propose the polarimetric interferometry calibration in two steps: the relative calibration between different polarization pairs and the usual interferometric calibration. Since the polarimetric interferometry signature can be relatively minute, it is necessary to perform the relative calibration precisely. Then, the usual interferometric calibration can be applied to one polarization data and subsequently all polarization combinations will be calibrated.

Eight radar measurements are involved in the polarimetric interferometry calibration: $s_{hh}^t, s_{hv}^t, s_{vh}^t, s_{vv}^t, s_{hh}^b, s_{hv}^b, s_{vh}^b$ and s_{vv}^b where the superscripts t and b denote the top and the bottom antennas, respectively. For the backscattering image, $s_{hv} = s_{vh}$; therefore, three interferograms are used derived for calibration: ϕ_{hh}, ϕ_{vv} and ϕ_{hv} . The differential interferogram has all necessary information for relative polarization calibration. Mathematically,

$$\begin{aligned}\Delta_{hhvv}(r, a) &= \phi_{hh}(r, a) - \phi_{vv}(r, a) \\ &= C_{hhvv} + B_{hhvv}(r, a) + S_{hhvv}(r, a) + M_{hhvv}(r, a) + n_{hhvv}(r, a)\end{aligned}\quad (5)$$

$$\begin{aligned}\Delta_{hhhv}(r, a) &= \phi_{hh}(r, a) - \phi_{hv}(r, a) \\ &= C_{hhhv} + B_{hhhv}(r, a) + S_{hhhv}(r, a) + M_{hhhv}(r, a) + n_{hhhv}(r, a)\end{aligned}\quad (6)$$

$$\begin{aligned}\Delta_{hvvv}(r, a) &= \phi_{hv}(r, a) - \phi_{vv}(r, a) \\ &= C_{hvvv} + B_{hvvv}(r, a) + S_{hvvv}(r, a) + M_{hvvv}(r, a) + n_{hvvv}(r, a)\end{aligned}\quad (7)$$

where C is the constant phase (radar channel differential phase), B is the phase due to baseline vector difference, S is the phase due to the different scattering mechanism, M is the multi-path phase, and n represents the thermal noise difference. If we average Δ in the along track direction, the scattering related phase difference S and the radar noise term n will be significantly reduced. That is, $\langle S \rangle_a \approx \langle n \rangle_a \approx 0$.

Since polarimetric interferometry implements the ping-pong mode, the phase B can be expressed in terms of the differential baseline vector $\delta\vec{B}$ as

$$B(r, a) = \frac{4\pi}{\lambda} \hat{n} \cdot \delta\vec{B} \quad (8)$$

Since two (top antenna and bottom antenna) images are co-registered in the along track direction, the differential baseline vector can be written as

$$\delta\vec{B} = \delta B_c \hat{c} + \delta B_x \hat{h} \quad (9)$$

The look vector \hat{n} is in the direction of the Doppler centroid used for the data processing and it is given by

$$\begin{aligned}\hat{n} &= (-\sin \theta \sin \theta_y - \cos \theta \cos \theta_y, \sin \theta_p) \hat{s} \\ &\quad + (-\sin \theta \cos \theta_y + \cos \theta \sin \theta_y, \sin \theta_p) \hat{c} + \cos \theta \cos \theta_p \hat{h}\end{aligned}\quad (10)$$

where θ_p and θ_y are the pitch and the yaw angle, respectively. The resulting azimuth averaged phase are shown in Fig. 2 and Fig. 3.

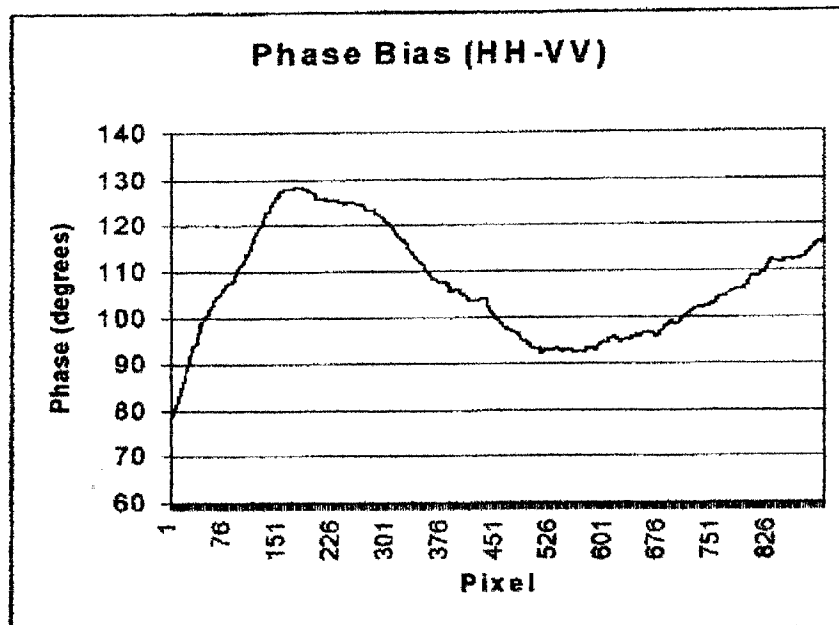


Fig. 2. Phase bias calculated by averaging the interferogram difference (HH-VV) in the azimuth direction. It includes the constant differential phase, the baseline difference phase, and the multi-path phase.

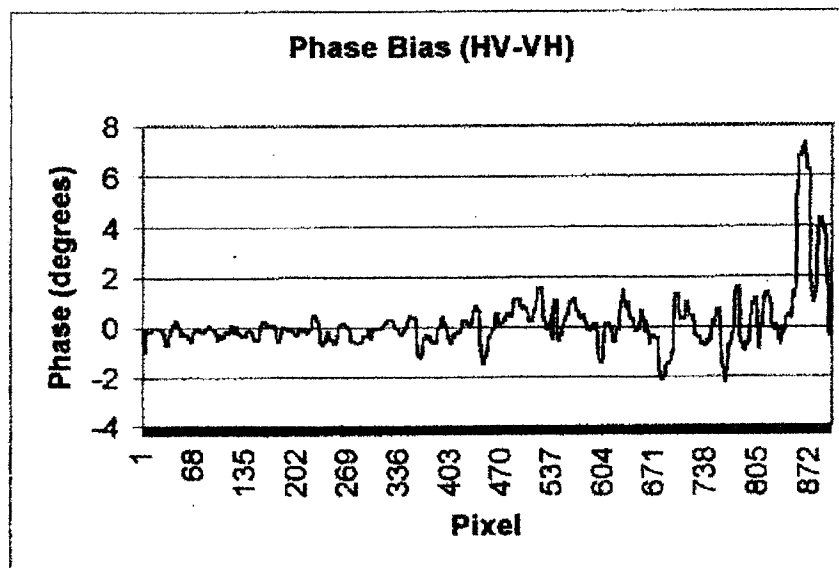
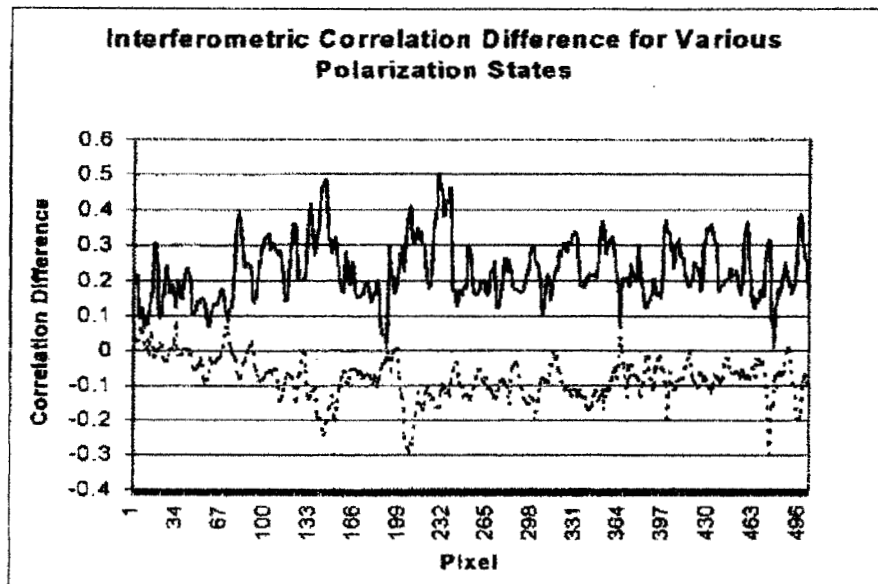


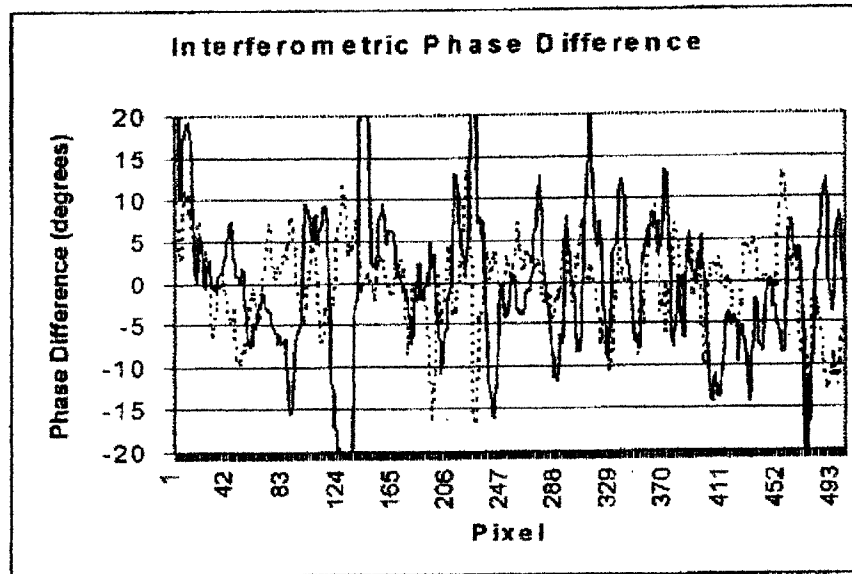
Fig. 3. Phase bias calculated by averaging the interferogram difference (HV-VH) in the azimuth direction. Notice that the difference is negligible.

Polarimetric Interferometry Signature

Recently, several successful demonstrations of estimating the tree height by using the amount of decorrelation were reported [2,3]. However, the exact relationship depends on the tree scattering structure. It is well known that the co-polarized phase difference can be used for classification since it comes from the scattering center displacement; however, for the forest area, the co-polarized phase appears to be random since the phase center displacement may be larger than the wavelength. This problem can be remedied if polarimetric interferometry is implemented and the interferometric phase difference is above the phase noise level. In order to show the feasibility of using various applications such as classification and the tree height estimation, we studied the POLTOP data collected in Ontario, California. The correlation and interferometric phase differences are shown in Fig. 4. The correlation coefficient in Fig. 4 has been compensated for the noise decorrelation in order to present the scattering related correlation only. The correlation coefficient is related to the scattering distribution and the interferometric phase represents the scattering center. This information provides the scattering structure in one pixel. In the vegetated area as shown in Fig. 4, it is clear that both scattering distributions and phase centers vary depending upon the radar polarization state.



(a) Interferometric correlation difference



(b) Interferometric phase difference

Fig. 4. Difference in observed correlation and interferometric phase measured at C-band with the POLTOP mode of the AIRSAR system. The dashed line represents the difference using the HH and VV combinations (HH-VV), and the solid line represents the difference when using the VV and HV polarization combinations (VV-HV). The phase difference of 10 degrees is approximately 2 meters in the height difference.

Conclusions

The NASA/JPL AIRSAR system was upgraded to collect polarimetric interferometric data. The preliminary analysis showed that the interferometric signature varies with the radar polarization. It is very important to understand the usefulness of the signature for various applications by comparing it with the ground truth.

References

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- [2] E. Rodriguez, T. R. Michel, and D. J. Harding, "Interferometric measurement of canopy height characteristics for coniferous forests, submitted for publication.
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